Synopsis

Ph.D in Physics

Development of Non-Metallic All Solid-State Sodium Battery using Sulfide Anode and Phosphate Cathode

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August 2024

Introduction

Over the past two decades, lithium ion batteries have majorly dominated the field of electrochemical energy storage devices. Still, difficulties such as high cost, thermal runaway, limitation on power density and inadequate Li source are the barriers for expedient energy storage devices. The technology employing alternate resources such as Na, Mg, K has been jaunted by researchers. Among all, sodium has gained focus due to the fact that sodium is abundant on earth's crust by 2.3% and India is the third country in producing sodium salts across the globe. For our country India, it is more appropriate to focus and work on Na-ion batteries with a purview to bring up a technology that is devoid of any restricted atmosphere for assembly and should be capable of sufficing the demand of energy as well. The development of room-temperature sodium-ion batteries (SIBs) has prompted significant research into suitable electrode materials. Among various electrode materials, sulfide and alloy based anode materials and polyanionic type cathode are prospective combination among sodium battery electrodes.

State of the art -Copper sulfide and Tin antimony Anodes

There are different types of anode materials viz., alloy, oxide, carbon, sulfide, and titanium-based materials employed for SIB applications. Majorly in the commercial application of LIBs, graphite anodes are employed since it delivers a laudable theoretical capacity of 372 $mAhg^{-1}$ appended with good electrochemical performance and longer cycle life **(Zhang et al., 2023**). However, in the context of SIBs, graphite does not have good alloying properties with Na^+ , which is thermodynamically unfavorable, and it delivers a low coulombic efficiency during charge–discharge cycling **(Veeraraghavan et al., 2002; Wang et al., 2014).** Other than graphite, hard carbon is widely employed as an anode material SIB applications due its highly stable nature of cycling **(Wang et al., 2014).** Still, hard carbon possesses a very low theoretical capacity of 300 $mAhg^{-1}$. Subsequently, metal sulfide-based anode materials are suitable candidates having excellent redox reversibility **(Xiao et al., 2016; Zhao et al., 2023**). Copper sulfide (CuS) is chosen as an anode material among all the other sulfide materials since the toxic levels are obviously lesser and attracts more attention.

Different methods of preparation of CuS such as hydrothermal, microwave-assisted, co-precipitation, and solid-state reaction methods **(Zhou et al., 2005; Nafees et al., 2011; Auyoong et al., 2013; Pejjai et al., 2019)** have been adapted by various researchers. Although several scientists have reported better performance for the hydrothermal method **(Auyoong et al., 2013)** due to their hierarchical structures for preparation of CuS, the shortfall with the methodology in

large-scale preparation cannot be ignored. On the other hand, the solid-state reaction method does not demand any solvent system and 90% of the yield is achieved with better feasibility for the scaling up process. There are very few reports, available for the preparation of CuS using the solid-state reaction method, and the compatibility for higher yield is remote.

In addition, an attempt is extended to study the role or synergy of the promising metal alloy anode, i.e., Tin antimony (Sn_2Sb_3). The alloy-based anodes are used in SIBs due to their high gravimetric and volumetric specific capacities **(Zheng et al., 2020).** Sn_2Sb_3-based alloy anodes are studied and found beneficial due to their high rate capability of 440 $mAhg^{-1}$ **(Ma and Prieto, 2019)**. However, tin antimony suffers from severe volume expansion **(Liu et al., 2013; Wu et al., 2014)** when alloying with sodium. Hence, an effort is made to pulverise the sulfide which is structurally stable without volume expansion issues and alloy-based material (CuS: Sn_2Sb_3) to increase the specific capacity.

State of the art – Sodium iron phosphate

Sodium iron phosphate ($NaFePO_4$) has reaped significant attention due to the high theoretical capacity of 154 $mAhg^{-1}$, environmental friendliness, and thermal stability. There are two mineral forms of $NaFePO_4$ i.e., Maricite and Olivine. Maricite-structured $NaFePO_4$ is distinct from the more commonly studied Olivine structure. Maricite phase consists of Sodium (Na) at octahedral sites and Iron (Fe^{2+}/ Fe^{3+}) at tetrahedral sites tuning up a three dimensional framework with high thermal stability but is electrochemically inactive phase. The maricite structure offers more stable framework that can accommodate sodium ions if altered can lead to improved electrochemical performance.

Hence this study focusses on the preparation of maricite $NaFePO_4$ using sol-gel method and its utilization as a cathode with the addition of trivalent and tetravalent dopants (La^{3+} and Zr^{4+}) to improve the electrochemical performance.

Problem Statement

- Metallic anodes demand controlled atmosphere for battery fabrication. Identification of suitable non-metallic anodes is in demand.
- Among non-metallic anodes, CuS and Sn_2Sb_3 are unexplored in Sodium All Solid-State Batteries.
- $NaFePO_4$ (NFP) is similar to $LiFePO_4$ that has higher operating voltage of 3.4-4.2 V.
- $NaFePO_4$ exists in two phases i.e., Maricite and Olivine. Maricite phase is an

electrochemically inactive phase with higher theoretical capacity of 154 $mAhg^{-1}$ hence conversion of maricite phase into electrochemically active phase is the challenge.

Objective and Scope of the research work:

- To construct a non-metallic All Solid State Sodium Battery using sulfide and phosphate cathode
- To evaluate the performance of CuS and the effect of pulverization Sn_2Sb_3 and evaluate the role of the prepared carbon in the electrochemical CuS anode.
- To improve the performance of CuS by the addition of different carbon sources.
- To prepare Sodium iron phosphate cathode ($NaFePO_4$) with trivalent and tetravalent dopant La^{3+} and Zr^{4+} and evaluate the suitability to SIBs.
- To construct All Solid-State Sodium Battery with different combinations of prepared anodes with pure $NaFePO_4$ and the best performing 0.02 Zr doped $NaFePO_4$.

Methodology:

- To prepare CuS using two different methods viz., co-precipitation method and solid-state reaction method and analyse its electrochemical performance.
- To evaluate the effect of pulverization of CuS with tin antimony (Sn_2Sb_3).
- To prepare a sodium alginate derived bio-carbon and evaluate the suitability to SIBs.
- To improve the performance of CuS by the addition of different carbon sources.
- To prepare Sodium iron phosphate cathode ($NaFePO_4$) with trivalent and tetravalent dopant La^{3+} and Zr^{4+} and evaluate the suitability to SIBs.
- To construct All Solid-State Sodium Battery with different combination of prepared CuS based anodes with pure $NaFePO_4$ and the best performing cathode, 0.02 Zr doped $NaFePO_4$**.**

The thesis is presented as five chapters with Results and Discussion possessing four phases. The layout of the thesis with the findings of investigations are briefly discussed below. The chapters are organized as follow:

1. Introduction
2. Review of Literature
3. Materials and Methods
4. Results and Discussion

Phase I: Characterization of CuS Anode and Pulverised CuS with Sn_2Sb_3

Phase II: Influence of Different Carbon Sources in Cus Anode and Pulverisation with Sn_2Sb_3

Phase III: Characterization of Pure Sodium iron phosphate ($NaFePO_4$) With Lanthanum and Zirconium Dopants

Phase IV: All Solid-State Device Assembling and Characterisation

5. Summary and Conclusions

Chapter-I

Introduction: In Chapter I, the importance of Sodium-ion batteries, as well as the need and evolution of energy storage devices are discussed. Various anode and cathode materials employed in sodium-ion batteries are listed with details and major motivation, objective and novelty of the work is presented in this chapter.

Chapter-II

Review of Literature: A detailed survey of literature on Sodium-ion batteries with the chosen anode and cathode are given in Chapter-II. The extensive research works available on sulfide, alloy based anode and phosphate type cathode materials are collectively enlisted. In this chapter, various parameters that can be used to improve the performance of electrode materials are thoroughly discussed following the published works in this arena.

Chapter -III

Materials and Methods: The necessary procedural aspects involved in the preparation of Copper sulfide, Tin antimony and carbon incorporated CuS, preparation of pure Sodium iron phosphate, Lanthanum and Zirconium doped $NaFePO_4$ are detailed in this chapter.

Preparation of Copper sulfide and Tin antimony: Synthesis of copper sulfide using two different methods are chosen viz., co-precipitation (CuS-CP) and solid-state reaction method (CuS (SSR)) is given. The details of pulverization of CuS anode with Tin antimony alloy i.e., CuS (CP): Sn_2Sb_3 and CuS (SSR): Sn_2Sb_3 named as P1-CuS and P2-CuS are elaborated.

Preparation of Carbon added Copper sulfide: Variety of carbon prepared from different sources of carbon and incorporated in CuS. The different sources are PVA, PVP, CB, AC and SAC and the way of preparation of these carbon in CuS are deliberated here.

Preparation of Sodium iron phosphate: Synthesis of pure $NaFePO_4$ with La^{3+} and Zr^{4+} dopants by sol-gel method are presented in Chapter -III.

Chapter- IV

Results and Discussion:

This chapter is divided into four phases. The results are shown in the following phases with the corresponding results and discussions as follows:

Phase I Characterization of CuS Anode and Pulverised CuS with Sn_2Sb_3

Phase II Influence of different carbon sources in CuS Anode and pulverisation with Sn_2Sb_3

Phase III Characterization of Pure Sodium iron phosphate ($NaFePO_4$) and Lanthanum and Zirconium doped $NaFePO_4$

Phase IV All Solid-State device assembling and Characterisation

Phase I

Characterization of CuS Anode and Pulverised CuS with Sn_2Sb_3

In this chapter, CuS has been prepared by two different methods viz., co-precipitation method and solid-state reaction method. CuS from both methods are pulverised in equal ratio with Tin antimony and the analysis and interpretations of pulverised samples are detailed in this chapter.

Important results:

Copper sulfide (CuS) anodes are widely a part of interest in Sodium-ion batteries owing to low-cost and good electrochemical properties. The theoretical capacity of CuS is 560mAhg^{-1} and two-electron process is involved during electrochemical cycling. CuS is investigated as anode in Sodium-ion Batteries using different methods of synthesis in this work, and the samples have been evaluated using X-Ray Diffraction (XRD), Raman, Field Emission Scanning Electron Microscopy (FESEM)- Energy Dispersive X-Ray Analysis (EDAX), High-Resolution Transmission Electron Microscopy (HRTEM), X-Ray Photoelectron Spectroscopy (XPS), Cyclic Voltammetry (CV), Galvanostatic Charge-Discharge analysis (GCD) and Electrochemical Impedance Spectroscopy (EIS). The intermetallic alloy formation in the sample P1-CuS is evident from the CV analysis which may be due to the disordered structure. The structural aspects of pulverisation in the sample P2-CuS indicates a tetrahedral skewed matrix of CuS (SSR) with a layered structure and a larger cavity which is highly beneficial for Na-ion charge transport mechanism. The AC Impedance study shows higher total electrical conductivity of 2.31x10^{-4} Scm^{-1} for the sample P2-CuS. An initial discharge capacity value of 480 mAhg^{-1} at 0.1C rate is obtained without any dissolution of active material in the case of P2-CuS.

Phase-II

Influence of different carbon sources in CuS Anode and pulverisation with Sn_2Sb_3

An attempt of carbonising CuS with different carbon sources such as Polyvinyl alcohol (PVA), Polyvinylpyrollidone (PVP), carbon black (CB), Activated Carbon (AC) and sodium alginate derived bio-carbon (SAC) are synthesized by Solid-State Reaction Method. Sodium alginate carbon is prepared and has been added to CuS. Promotion in reaction kinetics is expected which may provide higher capacity to be employed as an anode in Sodium-ion Batteries and the results on pulverization is also discussed in this phase.

Important results:

Aim of carbon addition to CuS is to improve the performance of the anode while pulverising with Sn_2Sb_3. Different carbon sources such as PVA, PVP, Carbon Black (CB), Activated carbon (AC) are chosen at the first level to find the best source of carbon compatible to CuS. To analyze the performance of the material, XRD, Raman, FESEM-EDAX, HRTEM, BET, XPS, CV, GCD and EIS characterizations are carried out. And the activated carbon (AC), a source of a petroleum product is found to be the best source of carbon with a same structure as that of CuS. CuS (AC) exhibits nanorod like morphology with a specific capacity of 151 $mAhg^{-1}$ with a capacity retention of 80%. And further, synthesis of bio-carbon from sodium alginate source shows crystallinity and with Raman characterization, D and G bands are observed. The carbon when added to CuS shows a stable hexagonal structure and the porous nature is observed from the FESEM analysis. From the BET analysis, a type III isotherm without hysteresis is seen that is favorable for non-reacting surface that can lead to stable surface without intermediary reaction thus expecting better charge collection. The calculated pore volume by BJH method is 0.051 $cm^3 g^{-1}$ and average pore diameter is 2.49 nm. The CuS (SAC) is observed as an average pore diameter. CuS (SAC) shows an initial discharge capacity of 442 $mAhg^{-1}$ at 0.1 Ag^{-1} with a capacity retention of 75% for 500 cycles. And the pulverised sample CuS (SAC): Sn_2Sb_3 shows an initial discharge of 650 $mAhg^{-1}$ with a capacity retention of 84.6% for 2000 cycles which is higher among all the anode samples.

Phase- III

Characterization of Pure Sodium iron phosphate ($NaFePO_4$) and Lanthanum and Zirconium doped $NaFePO_4$

Maricite phase of $NaFePO_4$ exhibits theoretical capacity 154 $mAhg^{-1}$ and this phase is said to be electrochemically inactive, hence studies are focussed on enhancing the properties of

$NaFePO_4$ due to structural stability and as alternate to volume expansion issue seen in Olivine NFP. Lanthanum exhibits a trivalent state and Zirconium of tetravalent state are favorable on doping in the Fe site on the basis of equivalent ionic radii. Hence, an attempt is made to synthesize five different concentrations of La^{3+} and Zr^{4+} $NaFe_{(1-x)}La_x/Zr_xPO_4$ (x=0.02, 0.04, 0.06, 0.08 and 0.1) and are discussed detailed in this phase.

Important results:

The prepared pure and doped samples of cathode are subjected to XRD, Raman, FESEM-EDAX, HRTEM, BET, CV, GCD, EIS, XPS and NMR characterizations. All the pure and doped samples remains in the same structure of orthorhombic with Pnma space group indicating a structural stability. Both La doped and Zr doped sample shows the presence of characteristic bonds of $NaFePO_4$ as observed from the Raman aanalysis. FESEM analysis shows a nanoplate like morphology in pure sample and the same morphology has been preserved only for 0.02 La and Zr dopant which further agglomeration for higher concentrations of La and Zr. The CV and GCD results of NFP-La0.02 sample shows a higher capacity of 116 mAh g^{-1} over 2000 cycles achieving 75.4% of theoretical capacity. In 0.02 Zr is doped NFP, a higher capacity of 146 $mAhg^{-1}$ which is 93% achievement of theoretical capacity is obtained with a capacity retention of 89 % which is higher among all the doped samples of NFP.

Phase IV

All Solid-State device assembling and Characterization

In the present work, considering the superiority of anode and cathode materials discussed in previous phases of research work, CuS (SAC): Sn_2Sb_3 anode and NFP-Zr 0.02 cathode have been finalized on scrutinizing the previously presented combination of anodes and cathodes as prospective- active counterparts for all solid state Na batteries (ASSIBs). On the other hand, a standard PVA-NaOH solid electrolyte membrane has been chosen as the matching electrolyte for laboratory prototype testing. The prepared anode materials are assembled with pure NFP and NFP-Zr 0.02 to compare the performance of the devices.

Important Results: All the anode combinations are assembled with respect to pure NFP and best performing cathode NFP-Zr 0.02. The CV, GCD and EIS studies are carried out to study the performance of all the devices. CuS (SAC): Sn_2Sb_3 versus NFP-Zr 0.02 full cell delivered a higher performance with a open circuit voltage of 1.3V with a higher specific capacity of 167 $mAhg^{-1}$ and higher energy density of 117 $WhKg^{-1}$ which is notable in the non-metallic type All Solid-State Sodium Battery. Usually a metal anode or cathode are employed in either side of

ASSIBs. Here in our work no metallic components are used in either side of a battery which primarily consists of non-metallic compounds and hence it is important point to be noted.

Salient findings in the study:

- CuS performance is favorable when CuS is prepared using Solid-state reaction method than co-precipitation method.
- Sodium alginate derived bio-carbon when added to CuS shows a higher capacity of 442 $mAhg^{-1}$ at a current density of 0.1 Ag^{-1} over 500 cycles among different sources of carbon.
- Pulverisation of CuS (SAC) with Tin antimony is found to be best anode with a higher capacity of 653 $mAhg^{-1}$ which remains stable for 2000 cycles with higher capacity retention of 84.6%.
- NFP with Zr 0.02 dopant exhibits a higher capacity of 146 $mAhg^{-1}$ at 0.1 Ag^{-1} over 2000 cycles with a capacity retention of 86.4% among all the cathode samples.
- Among the full cells exhibited, CuS (SAC): Sn_2Sb_3 ||NFP-Zr0.02 exhibits a higher OCV of 1.34 V with a higher capacity of 167 $mAhg^{-1}$ at 0.1 Ag^{-1} over 2000 cycles.
- The objective of constructing All-Solid State Sodium ion Battery without any metal has been accomplished from this study.

Conclusions

This work is mainly dedicated to an easy and simple pulverisation process of CuS, a sulfide anode with Tin antimony alloy. The performance enhancement of CuS anodes by addition of different carbon sources viz., Activated carbon (AC), Sodium Alginate derived carbon (SAC) are studied and the pulverisation effects are also discussed. In addition to the anode, polyanionic cathode $NaFePO_4$ (NFP) has been chosen and analysed for all the results. To improve the performance of pure maricite phase of $NaFePO_4$, two different dopants La^{3+} and Zr^{4+} has been studied. Finally the suitable combination CuS (SAC): Sn_2Sb_3 versus 0.02 Zr doped NFP cathode has been successfully assembled as an All Solid-State Battery and found to be superior among all other devices.

Publications:

International Journals

1. Papers Effect of pulversation of sulfide and tin antimonide anodes for Sodium-ion Batteries, **P. Priyanka,** B. Nalini, G.G. Soundarya, P. Christopher Selvin, Dimple P. Dutta, Frontiers in Energy Research, 11, 2023. DOI : 10.3389/fenrg.2023.1266653.

2. A Potential Cathode for Quasi Solid-State Sodium-Ion Batteries with Trivalent Doping of La^{3+} in Sodium Iron Phosphate, **P. Priyanka,** B. Nalini, Asian Journal of Chemistry, 36 (6):1393-1402, 2024. DOI: 10.14233/ajchem.2024.31662.

To be Published and present status

1. Contribution of Sodium Alginate derived biomass carbon in CuS towards enhance electrochemical performance for Sodium-ion Batteries, **P. Priyanka,** B. Nalini, G.G. Soundarya, P. Balraju, Journal of Materials Science: Materials in Electronics
   Status : Under Review
2. **Electrochemical study on impact of different carbon sources on CuS anodes for Sodium-ion Batteries, P. Priyanka,** B. Nalini, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects
   Status: Under Review

Conferences or Workshops attended

1. "62^{nd} DAE Solid State Symposium", organized by Bhabha Atomic Research Center, Mumbai on 25.12.2017 to 30.12.2017.
2. Workshop on DST Curie sponsors One day Workshop on "Nanomaterials Fabrication and Devices", conducted by Department of Physics, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore on 15.02.2018.
3. "One day Lecture Workshop on Theoretical Physics" organized by Department of Physics, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore on 26.09.2018.
4. Workshop conducted by NRIIC, PSG Institute of Advanced Studies, Coimbatore on "Sensitisation Program on Scanning Electron Microscopy" in 13.04.2019.
5. One day seminar on " Intellectual Property Right and Patenting" organised by Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, 11.10.2019.
6. Workshop on "Familiarization workshop series on Electrochemical workstation" conducted on Sri Ramakrishna Engineering College, Department of Nanoscience and Technology, 06.11.2019.
7. Workshop on DST-CURIE Sponsored Workshop on "X-ray Crystallography" organised by Department of Physics, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, 11.02.2019.
8. Webinar on "Nanomaterials for Energy conversion and storage" organized by SNS College of Technology, Coimbatore, 07.05.2020.
9. Webinar on "Functional Novel Materials for Electrochemical Sensors and Energy Storage Devices" organized by Thiagaraja College , Madurai in collaboration with MING CHI University of Technology, New Taipei City, Taiwan, 15.05.2020.
10. Webinar on "Electron microscopy: an essential tool for Nanomaterials Characterization" organized by Hindustan College of Arts and Science, Coimbatore, 29.05.2020.

11. Two days webinar on “Information Access for Professional Development and Research Collaboration” on 03.06.2020 and 04.06.2020 organized by Library, School of Education, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, collaboration with the INFLIBNET Centre, Gandhinagar, Gujarat.
12. Webinar on “Green Energy and Technology" (GET 2020) conducted by King's Engineering College, Chennai on 19.06.2020.
13. International webinar on “Basics of IR and Raman Spectroscopy organized by Department of Physics, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, 24.06.2020.
14. International webinar on “Sample preparation for TEM and data analysis” organized by Department of Materials Science, School of Chemistry, Madurai Kamaraj University, Madurai, 30.06.2020.
15. “Raman Spectroscopy: Basics, Instrumentation and Application” organized by Centre for Nanoscience and Nanotechnology, Sathyabama Institute of Science and Technology, Chennai on 02.07.2020 and 03.07.2020.
16. International webinar on “Advanced materials for Energy Storage Applications” organized by Research Centre of Physics, Fatima College, Madurai, 13.07.2020 to 15.07.2020.
17. DST-INSPIRE to join the “Science, Technology, and Innovation Policy 2020 (STIP) organized by Science, Technology, and Innovation Policy 2020 (STIP) Consultation Session with Young Scientists lead by Prof. K. Vijay Raghavan, Principal Scientific Adviser, 16.07.2020
18. National webinar on “Research Methodology” organized by Loyola college, Chennai on 17.07.2020.
19. webinar on “ Research Ethics, Copyright and Plagiarism” under UGC STRIDE programme organized by Mizoram University on 20.07.2020.
20. International webinar on “Nanotech applications” organized by Department of Science, St. Joseph’s College of Engineering, Chennai on 24.07.2020 and 25.07.2020.
21. International virtual seminar on “ Recent Advance Materials in Energy Applications” organized by Sathyabama Institute of Science and Technology, Chennai on 30.07.2020 and 31.07.2020
22. International virtual seminar on “ Advanced Materials for Energy Conversion and Storage” organized by Centre for Nanoscience and Nanotechnology, Sathyabama Institute of Science and Technology, Chennai on 10.08.2020 to 13.08.2020.
23. Webinar on “Carbon Allotrope as Anode Material for Lithium Ion Battery” organized by Orion Centre for Physics on 15.08.2020.
24. International Virtual Conference on “Supercapacitors and Batteries for Future Avenues (ICSBFA 2020)” organized by Bharathidasan University, Trichy on 08.09.2020 and 09.09.2020.
25. Webinar on “Enhancing manuscript with endnote” organised by Library, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore on 14.09.2020.

Papers presented in Conferences

1. International Conference on Advanced Materials (ICAM) on the topic of "A Novel method for generating tricolor emission using SnSb alloy" organised by PSGR Krishnammal College of Arts and Science, Coimbatore on 03.01.2018 to 05.01.2018.
2. International Conference on Advance Materials for Sustainable Energy and Sensors (INCAMSES-2019) on the topic of "Solid-state synthesis of copper sulfide nanoparticles as an anode for sodium-ion batteries" organised by Alagappa University, Karaikudi, 16.07.2019 and 17.09.2019.
3. DST-SERB Sponsored National Conference on "Transition based Sodium-ion batteries for Ultrafast Energy Storage Systems (NCTMSIB'19)" - Best paper Award in the topic of "Pulverization of CuS: Sn_2Sb_3 : a potential anode for Sodium-ion battery" organised by Dr.N.G.P Institute of Technology, Coimbatore on 13.11.2019.
4. International Web Conference on Advanced Materials Science and Engineering (ICAMSE-2020) on the topic of "Performance enhancement of carbonized copper sulphide through glucose as a carbon source" Department of Physics, Bannari Amman Institute of Technology, Sathyamangalam on 11.09.2020 and 12.09.2020.
5. 6^{th} International Conference on Nanoscience and Nanotechnology ICONN -2021 on the topic of "Evaluation of Novel electrolytic bio-polymer Membrane for Na Batteries" orgainsed by SRM Institute of Science and Technology on 01.02.2021 to 03.02.2021.
6. 65^{th} DAE- Solid State Physics Symposium (DAE-SSPS) in the research topic of "Evaluation of Xanthan gum with additive salts as an electrolyte for Sodium-ion Batteries" organised by Bhabha Atomic Research Centre (BARC), Mumbai on 15.12.2021 to 19.12.2021.

Book chapter published

1. Basic Aspects of Design and Operation of All-Solid-State Batteries,
Solid State Batteries, Design, Challenges and Market Demands,
P. Priyanka, B.Nalini & P. Nithyadharseni in Springer, Cham.
https://doi.org/10.1007/978-3-031-12470-9_1, 2022.

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